FINAL STATE INTERACTION IN NEUTRON DEUTERON CHARGE EXCHANGE REACTION AT SMALL TRANSFER MOMENTUM

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Abstract

Analysis of the $nd \to p(nn)$ reaction in a Gev-energy region is performed in the framework based on the multiple-scattering theory for the few nucleon system. The special kinematic condition, when momentum transfer from neutron beam to final proton closes to zero, is considered. The possibility to extract the spin-flip term of the elementary $np \to pn$ amplitude from nd-breakup process is investigated. The energy dependence of the ratio $R = \frac{d\sigma_{nd}}{d\Omega}/\frac{d\sigma_{np}}{d\Omega}$ is obtained taking account of the final state interaction two outgoing neutrons in $^1S_0$-state.

1 Introduction

The nucleon- deuteron charge exchange reaction is the subject of the investigation in the set of the experiments, which are started in VBLHE JINR at STRELA and DELTA SIGMA [1] setups and in COSY[2] at ANKE spectrometer. The experiments are performed in the special kinematics, when transfer momentum from initial nucleon to outgoing fast nucleon is close to zero. The goal of these experiments is to extract the additional information about spin dependent part of the elementary $np \to pn$ process from nucleon-deuteron reaction. This idea was suggested by Pomeranchuk [3] already in 1951. Later, it was shown, that in the plane-wave impulse approximation (PWIA) the differential cross section and tensor analyzing power T_{20} in the dp-charge exchange reaction are actually fully determined by the spin-dependent part of the elementary $np \to pn$ amplitudes [4], [2].

However, under kinematical conditions, when momentum of the emitted fast nucleon has the same direction and value as the beam (in the deuteron rest frame), and relative momentum of the two slow nucleons is small, the final state interaction (FSI) effects play very important role. The study of the FSI influence is the goal of this paper.

Here the $nd \to pnn$ reaction is considered in kinematics of the DELTA SIGMA experiment [1], when outgoing proton has the same direction as projectile neutron and transfer momentum is close to zero. The kinetic energy of the initial neutron varies from 0.8 up to 1.3 GeV. The analysis has been performed in the deuteron rest frame. The theoretical approach is based on the Alt-Grassberger-Sandhas formulation of the multiple-scattering theory for the three-nucleon system. The matrix inversion method has been applied for description of the two slow neutrons interaction.

2 Theoretical formalism

In accordance to the three-body collision theory, the amplitude of the neutron deuteron charge exchange reaction,

$$n(\vec{p}) + d(\vec{0}) \rightarrow p(\vec{p_1}) + n(\vec{p_2}) + n(\vec{p_3}) \tag{1}$$

is defined by the matrix element of the transition operator U_{01}

$$U_{nd\rightarrow pnn} \equiv \sqrt{2} < 123|[1-(1,2)-(1,3)]U_{01}|1(23) >= \delta(\vec{p}-\vec{p}_1-\vec{p}_2-\vec{p}_3)\mathcal{J}. \tag{2}$$

As consequence of the particle identity in initial and final states the permutation operators for two nucleons (i,j) appear in this expression.

As it was shown in ref.[5], the matrix element $U_{nd\rightarrow pnn}$ can be presented as

$$U_{nd\rightarrow pnn} = \sqrt{2} < 123|[1-(2,3)][1+t_{23}(E-E_1)g_{23}(E-E_1)]t_{12}^{sym}|1(23) >, \tag{3}$$

where the operator $g_{23}(E-E_1)$ is a free propagator for the (23)-subsystem and the scattering operator $t_{23}(E-E_1)$ satisfies the Lippmann-Schwinger (LS) equation with two-body force operator V_{23} as driving term

$$t_{23}(E-E_1) = V_{23} + V_{23}g_{23}(E-E_1)t_{23}(E-E_1). \tag{4}$$

Here E is the total energy of the three-nucleon system $E = E_1 + E_2 + E_3$.

Let us rewrite the matrix element (3) indicating explicitly the particle quantum numbers,

$$U_{nd\rightarrow pnn} = \sqrt{2} < \vec{p_1}m_1\tau_1, \vec{p_2}m_2\tau_2, \vec{p_3}m_3\tau_3|[1-(2,3)]\omega_{23}t_{12}^{sym}|\vec{p}m\tau, \psi_{1M_d00}(23) >,$$

where $\omega_{23} = [1+t_{23}(E-E_1)g_{23}(E-E_1)]$ and the the spin and isospin projections denoted as m and τ, respectively. The operator t_{12}^{sym} is symmetrized NN-operator, $t_{12}^{sym} = [1-(1,2)]t_{12}$.

Under kinematical conditions, when transfer momentum $\vec{q} = \vec{p}-\vec{p_1}$ is close to zero, one can anticipate that the FSI in the $^1S_0$ state is prevalent at comparatively small p_0-values. In such a way we get the following expression for the amplitude of the nd charge exchange process [6]

$$\mathcal{J} = \mathcal{J}_{PWIA} + \mathcal{J}_{^1S_0}$$

$$\begin{aligned}\mathcal{J}_{PWIA} = {} & < LM_L1\mathcal{M}_\mathcal{S}|1M_D > u_L(p_0)Y_L^{M_L}(\widehat{p_0}) \\ & \{< \frac{1}{2}m_2'\frac{1}{2}m_3|1\mathcal{M}_\mathcal{S} >< m_1m_2, \vec{p}_1, \vec{p}_0+\vec{q}/2|t^0-t^1|\vec{p}, \vec{p}_0-\vec{q}/2, mm_2' > - \\ & < \frac{1}{2}m_2'\frac{1}{2}m_2|1\mathcal{M}_\mathcal{S} >< m_1m_3, \vec{p}_1, \vec{p}_0-\vec{q}/2|t^0-t^1|\vec{p}, \vec{p}_0+\vec{q}/2, mm_2' >\}\end{aligned} \tag{5}$$

$$\begin{aligned}\mathcal{J}_{^1S_0} = {} & \frac{(-1)^{1-m_2-m_2'}}{\sqrt{4\pi}}\delta_{m_2\ -m_3} < \frac{1}{2}m''\frac{1}{2}-m_2'|1M_D > \\ & \int d\vec{p_0}' < m_1m_2', \vec{p}_1, \vec{p}_0'+\vec{q}/2|t^0-t^1|\vec{p}, \vec{p}_0'-\vec{q}/2, mm'' > \psi_{00}^{001}(p_0')u_0(|\vec{p}_0'-\vec{q}/2|).\end{aligned} \tag{6}$$

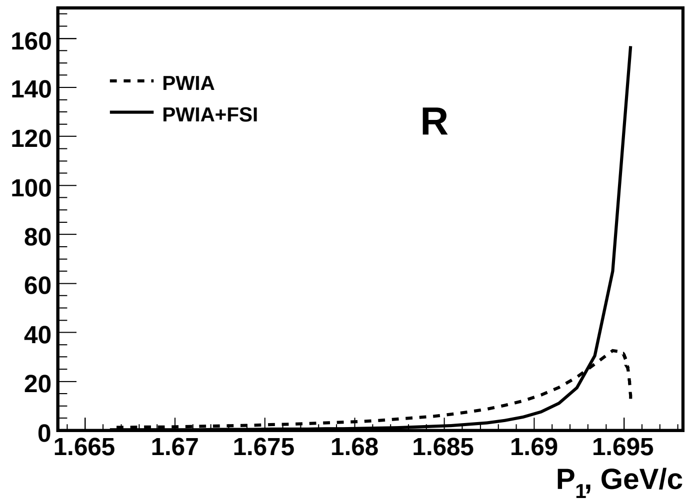

Figure 1: R ratio *vs.* the fast proton momentum p_1 at $T_n = 1\ GeV$

The wave function of the final pp-pair $\psi_{00}^{001}(p_0')$ can be expressed by a series of δ-functions

$$\psi_{00}^{001}(p_0') = \sum_{j=1}^{N+1} C^{001}(j) \frac{\delta(p_j - p_0)}{p_j^2}, \tag{7}$$

where $p_j (j = 1, N)$ are the grid points associated with the Gaussian nodes over $[-1, 1]$ and $p_{N+1} = p_0$ and $C(j)$ are the coefficients, which are determined from the solution of the linear algebraic equations system approximately equivalent to the Lippmann- Schwinger equation for two neutrons scattering [7].

Since the $q, p_0 \ll p, p_1$ and subintegral function is suppressed at high p_0', we can neglect by q, p_0, p_0' dependences of the high- energy np t-matrix. Then this vertex represents the free np elastic scattering at angle $\theta = \pi$ and t-matrix can be described by three independent amplitudes

$$t_{NN}^{cm}(\theta^* = \pi) = A + (F - B)(\vec{\sigma}_1 \hat{q}^*)(\vec{\sigma}_2 \hat{q}^*) + B(\vec{\sigma}_1 \vec{\sigma}_2), \tag{8}$$

where $\hat{q}^*$ is the unit vector in the beam direction.

The cross section of the $nd \to pnn$ reaction is defined by the standard manner

$$\sigma = (2\pi)^4\ \frac{E}{p} \cdot \frac{1}{6} \int\ d\vec{p}_1\ d\vec{p}_2\ \delta(M_d + E - E_1 - E_2 - E_3)\ \ |\mathcal{J}|^2, \tag{9}$$

where $\vec{p}_3 = \vec{p} - \vec{p}_1 - \vec{p}_2$ and $E_3 = \sqrt{m^2 + (\vec{p} - \vec{p}_1 - \vec{p}_2)^2}$ and squared amplitude has the following form

$$|\mathcal{J}|^2 \approx \frac{1}{2\pi}\ \left(\frac{m+E}{2E}\right)^2 (2B^2 + F^2) \left\{ u(p_0) + \sum_{j=1}^{N+1}\ u(p_j) C^{001}(j) \right\}^2 \tag{10}$$

We get the factorization of the squared amplitude on the two parts. One of them depends on the deuteron and two slow neutrons wave functions. Other term corresponds to the spin-dependent component of the elementary $np \to pn$ cross section.

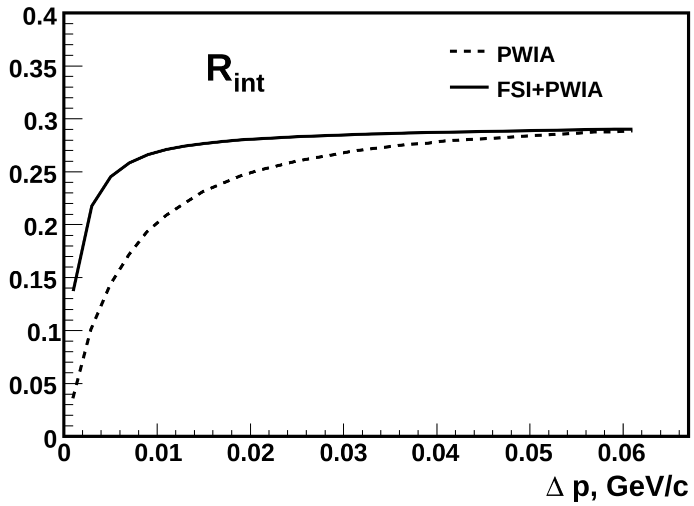

Figure 2: Integrated R ratio as a function of Δp at $T_n = 1\ GeV$

3 Results

Here we consider the ratio of the nd charge exchange differential cross section to the free np scattering differential cross section.

$$R = \frac{d\sigma(nd \to pnn)}{dp_1 d\Omega} / \frac{d\sigma(np \to pn)}{d\Omega} \tag{11}$$

This ratio is presented in Fig.1 as a function of the final proton momentum p_1.

The solid line,which corresponds to the full calculation, has a very sharp peak, when momentum p_1 is close to beam momentum p, or transfer momentum q is close to zero. This peak indicates the FSI contribution to nd differential cross section.

In this region the value of the R ratio varies in 10 times, while transfer momentum changes on few MeV. Since any experiment has the limited momentum resolution, we consider the R ratio integrated over p_1 in some region.

$$R_{int} = \int_{p-\Delta p}^{p} dp_1 R(p_1) = \int_{p-\Delta p}^{p} dp_1 \frac{d\sigma(nd \to pnn)}{dp_1 d\Omega} / \frac{d\sigma(np \to pn)}{d\Omega} \tag{12}$$

The integration limits change from $p - \Delta p$ up to maximal value p_1 equal p. The Δp is the difference between p and p_1. The integrated R-ratio is shown in Fig2. in dependence on the change of integration limits .

One can see, that the difference between PWIA and full calculation results is about 30% for Δp equal 10 MeV, about 15% for Δp equal 20 MeV and these lines are practically undistinguished, when Δp is equal 60 MeV.

The energy dependence of the integrated R ratio is presented in Fig.3. The integration has been performed for Δp equal 30 MeV. We investigate energy region only up to 1300 MeV, when the phase shift analysis data are exist. The dash- dotted line is obtained using the formula from ref.[8] with NN amplitude taken from recent phase shift analysis [9]. The difference between result obtained taking into account FSI and PWIA result is

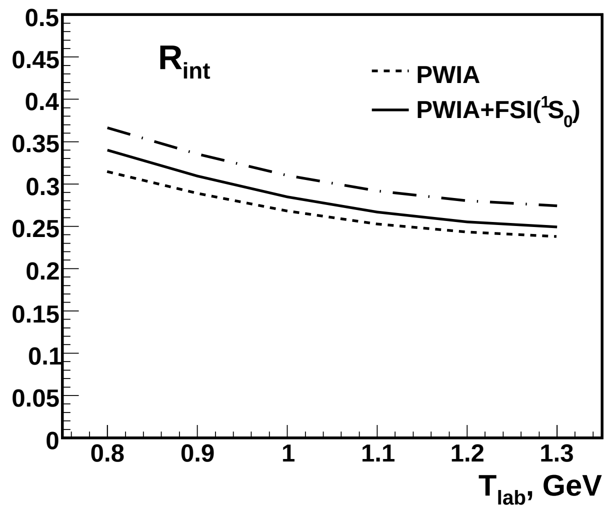

Figure 3: Energy dependence of the integrated R-ratio

about 10 % for kinetic energy 800 MeV and few per cent for kinetic energy 1300 MeV. Thus, the contribution of the FSI decreases, when the kinetic energy is increases.

4 Conclusion

In this paper the $nd \to p(nn)$ reaction has been studied at the neutron kinetic energy $T_n = 0.8 \div 1.3\ GeV$ in kinematics, when transfer momentum is close to zero. The R ratio of the nd differential cross section to the elementary $np \to pn$ one has been considered. It was shown, that the final state interaction play important role, although the contribution of the FSI decreases with the increasing energy. The factorization of the nd squared amplitude has been got, what allows us to extract the spin dependent part of the np charge exchange amplitude from the $nd \to p(nn)$. But obtained result will be dependent on the applied model for FSI description and choice of the deuteron wave function. As a consequence, the nd charge exchange reaction can not be used to define the precise value of the spin dependent part of the free np scattering. However it is possible to get some useful information about np charge exchange process (for example, sign, approximate value etc.).

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References

[1] V.I.Sharov, Czech.J.Phys.**55**, A289-A305 (2005)

[2] A.Kacharava, F.Rathmann (spokespersons) *et al.*, COSY proposal # 125, 2003

[3] I.Pomeranchuk, Doklady Academii Nauk USSR **78**, 249 (1951)

[4] B.S.Aladashvili *et al.* , Nucl.Phys. B**86**, 461 (1975)

[5] N.B.Ladygina, A.V.Shebeko, Few Body Syst.**33**, 49 (2003)

[6] N.B.Ladygina, A.V.Shebeko, Eur.Phys.J. A**22**, 29 (2004)

[7] Korchin, A. Yu., Shebeko, A.V.: Preprint KFTI 77-35, Kharkov 1977

[8] V.V.Glagolev *et al.*, Preprint JINR E1-99-280, Dubna, 1999; R.Lednicky, V.L.Lyuboshitz, V.V.Lyuboshitz, nucl-th/0302036, 2003

[9] http://gwdac.phys.gwu.edu